Hazard Profile - Tsunami

Introduction[1, 2, 3]

The Pacific Coast, Strait of Juan de Fuca, Puget Sound, and large lakes are at risk from tsunamis, trains of waves that threaten people and property along shorelines. Sudden raising or lowering of the Earth's crust during earthquakes generally causes a tsunami, although landslides and underwater volcanic eruptions also can generate them. Movements of the sea floor or lakebed, or rock fall into an enclosed body of water, displace the water column, setting off a series of waves that radiate outward like pond ripples.

Only as a tsunami approaches land does it become a hazard; in shallow water, it gains height as its waves slow and compress. Tsunamis do not resemble their usual icon, a towering wave with a breaking crest. Instead, they come onshore resembling a series of quickly rising tides, and they withdraw with currents much like those of a river. Swift currents commonly cause most of the damage from tsunamis. A Pacific Ocean tsunami can affect the entire Pacific basin, while a tsunami in inland waters can affect many miles of shoreline.

Tsunamis typically cause the most severe damage and casualties near their source. There, waves are highest because they have not yet lost much energy. The nearby coastal population often has little time to react before the tsunami arrives. Persons caught in the path of a tsunami often have little chance to survive; debris may crush them, or they may drown. Children and the elderly are particularly at risk, as they have less mobility, strength, and endurance.

A tsunami crosses the ocean at jetliner speeds, close to 600 miles per hour. The 1946 tsunami from Alaska's Aleutian Islands took less than five hours to reach Hawaii, where it killed 159 people. The 1700 tsunami from the Cascadia subduction zone along the Pacific Coast of Washington took about 10 hours to reach Japan, where it caused flooding and damage along 600 miles of the Pacific coast of Honshu.

Tsunami waves can continue for hours. In the ocean, other waves can follow the first wave within a few minutes or a few hours; later waves sometimes are larger. For example, the first wave to strike Crescent City, California, following the 1964 Alaska earthquake was 9 feet above the tide level; the second, 29 minutes later, was 6 feet above tide; the third was about 11 feet above the tide level; and the fourth, most damaging wave was more than 16 feet above the tide level. The third and fourth waves killed 11 people. Estimates of the damage range from $7.4 million to $16 million (in 1964 dollars). That same tsunami destroyed property in many areas along the coast from Alaska to California. In Washington, the largest wave entered Willapa Bay arrived about 12 hours after the first wave; the tsunami caused $105,000 (in 1964 dollars) in damage (see below).

Although the 1964 event was the largest 20th-century tsunami on the Washington coast, the state has its own sources of tsunamis, and these have produced great waves recorded geologically in the last few thousand years.

Recent Major Tsunamis Worldwide, 1946 - Present

Date	Origin	Effects	Deaths
April 1, 1946	Aleutian Trench	Damage to Alaska and Hawaii.	159
May 22, 1960	South-central Chile	From the 20th-century's largest earthquake, magnitude 9.5. Damage to Chile, Hawaii, and Japan.	1,500 (61 in Hawaii, 118 in Japan)
March 27, 1964	Anchorage, Alaska	From the second-largest earthquake of the 20th century, magnitude 9.2. Severe damage to south coast of Alaska. Deaths in Oregon and in Crescent City, California.	115
August 23, 1976	Celebes Sea	Southwest Philippines struck, devastating Alicia, Pagadian, Cotabato and Davao.	8,000
July 12, 1993	Japan Trench	Okushiri Island devastated.	200
July 17, 1998	Papua New Guinea, Bismarck Sea	Arop, Warapu, Sissano, and Malol Papua New Guinea devastated.	2,200

Tsunami Threat in Washington[4]

Washington's outer coast is subject to tsunamis generated by distant sources, such as earthquakes in Alaska and Chile, as well as from earthquakes in the Cascadia subduction zone. The Cascadia subduction zone contains a huge active fault that dips eastward beneath Washington's coast. This fault is a boundary between two tectonic plates. The fault has generated earthquakes of magnitude 8 or larger (great earthquakes) at least six times in the past 3,500 years, as shown by coastal and offshore geology. The most recent of these earthquakes occurred the evening of January 26, 1700. The tsunami it generated in Japan was probably 6 to 16 feet high, a size best explained by a Cascadia earthquake of magnitude 9. Computer models indicate that a Cascadia tsunami can be up to 30 feet in height and affect the entire Washington coast. Its wave train would begin to reach coastal communities in tens of minutes after the earthquake.

Washington's inland waters also are subject to tsunamis. For example, a landslide set off a tsunami in the Tacoma Narrows a few days after the 1949 Olympia earthquake. An earthquake in A.D. 900-930 on the Seattle Fault caused uplift that triggered a tsunami in central Puget Sound. Tsunamis from great Cascadia earthquakes probably account for several sand sheets on northwestern Whidbey Island and at Discovery Bay.

Probability of Occurrence

Great earthquakes in the North Pacific or along the Pacific coast of South America that generate tsunamis that sweep through the entire Pacific basin occur at a rate of about six every 100 years. Local earthquakes and landslides that generate tsunamis occur more frequently, although a specific rate of occurrence has not been calculated by scientists.

Examples of Tsunamis on Washington's Pacific Coast[5, 6, 7, 8]

While tsunamis have caused significant damage, deaths and injuries elsewhere in the world, only one significant tsunami struck the Washington coast in recent history. The 1964 Alaska earthquake generated a tsunami that resulted in more than $105,000 (in 1964 dollars) in damage. However, geologic investigations indicate that tsunamis have struck the coast a number of times in the last few hundred years.

1700 Cascadia Tsunami

The most recent Cascadia Subduction Zone earthquake, estimated magnitude 9, produced a tsunami on the Washington coast in 1700. The tsunami deposited sand on marshes, on what are now archaeological sites, and in lakes along the southern part of the coast. A sand sheet at Discovery Bay in the eastern Strait of Juan de Fuca also probably resulted from the 1700 tsunami.

In Japan, the 1700 tsunami began in the middle of night and continued until the following afternoon or evening. Its waves made the sea rise and fall like a swift series of tides. It drove villagers to high ground, drowned their paddies and crops, damaged their salt kilns and fishing shacks, entered a government storehouse, and ascended a castle moat. It destroyed dozens of buildings, including 20 houses consumed by a fire that the flooding started or spread. It set in motion a nautical accident that sank tons of rice and killed two sailors. It led samurai to give rice to villagers left hungry and to request lumber for those left homeless. It left a village headman wondering why no earthquake had warned of its coming.

1960 Chilean Tsunami

A magnitude 9.5 earthquake along the coast of Chile generated a tsunami that struck the Washington coast at Grays Harbor (small waves), Tokeland (two feet), Ilwaco (two feet), Neah Bay (1.2 feet), and Friday Harbor (0.3 feet). No damage occurred.

1964 Alaskan Tsunami

The tsunami generated by the March 27, 1964 Alaska earthquake was the largest and best-recorded historical tsunami on the southern Washington coast. Tsunami wave heights generally were greatest on the south coast, and smaller on the north coast; additionally, the tsunami was recorded inland in the Straight of Juan de Fuca (Friday Harbor), Puget Sound (Seattle), and the Columbia River (Vancouver).

Observations were made of the tsunami in Grays Harbor County at Westport, Joe Creek, Pacific Beach, Copalis, Grays Harbor City, and Boone Creek.

Recorded Height of Tsunami Wave from 1964 Alaska Earthquake

Wreck Creek Grays Harbor County	4.5 Feet	Neah Bay Clallam County	0.7 Feet
Seaview Pacific County	3.8 Feet	Taholah Grays Harbor County	0.7 Feet
Moclips Grays Harbor County	3.4 Feet	Hoh River Mouth Jefferson County	0.5 Feet
Ocean Shores Grays Harbor County	2.9 Feet	Friday Harbor San Juan County	0.4 Feet
La Push Clallam County	1.6 Feet	Vancouver Clark County	0.1 Feet
Ilwaco Pacific County	1.4 Feet	Seattle King County	0.1 Feet

Damages included debris deposits throughout the region, minor damage in Ilwaco, damage to two bridges on State Highway 109, a house and smaller buildings being lifted off foundations in Pacific Beach (the house was a total loss), and piling damaged at the Moore cannery near Ilwaco.

Inland Tsunamis[9, 10, 11, 12, 13]

A.D. 900-930 Tsunami

An earthquake sometime between 900 and 930 raised shores of central Puget Sound by 20 feet between the Duwamish River and Bremerton. The area of uplift included the floor of Puget Sound, which created a tsunami. In Seattle, the tsunami washed across West Point, where it deposited a sheet of sand. Farther north, it deposited a sand sheet at Cultus Bay on southern Whidbey Island and along tributaries of the Snohomish River between Everett and Marysville. Computer simulations of the tsunami show it reaching heights of 10 feet or more at the Seattle waterfront.

Early 1800s Camano Head Tsunami

Historical accounts among the Snohomish people describe a large landslide at Camano Head that sent a large wave south that toward Hat Island. According to tribal accounts, the landslide sounded like thunder, buried a small village and created a large volume of dust. The tsunami washed over the barrier beach at Hat Island, destroying homes or encampments and drowning many people. The accounts make no mention of ground shaking, suggesting that the slide was not associated with a large earthquake. Camano Head is at the south end of Camano Island in Puget Sound.

1890s Puget Island Tsunami

This tsunami occurred in the 1890s, but is not well documented. A landslide-triggered tsunami overran Puget Island in the Columbia River near Cathlamet. The wave killed one person.

1891 Puget Sound Tsunami

Water in Lake Washington and Puget Sound surged onto beaches two feet above the high water mark, rocking vessels that had just pulled away from wharves, and causing an elevator in one building to bump against the side of the shaft. The likely cause of this November 29 event was two earthquake shocks and submarine landslides.

1894 Commencement Bay Tsunami

A submarine landslide in the delta of the Puyallup River in Commencement Bay, Tacoma, caused a tsunami. These events carried away a railroad track and roadway, resulting in two deaths.

1949 Puget Sound Tsunami

A small landslide-generated tsunami struck the Point Defiance shoreline in the Tacoma Narrows on April 16, three days after a magnitude 7.1 earthquake weakened the hillside. According to local newspaper reports, an 11 million cubic yard landslide occurred when a 400-foot high cliff gave away and slid into Puget Sound. Water receded 20-25 feet from the normal tide line, and an eight-foot wave rushed back against the beach, smashing boats, docks, a wooden boardwalk, and other waterfront installations in the Salmon Beach area. The slide narrowly missed a row of waterfront homes struck by the tsunami.

Lake Roosevelt Tsunamis

Landslides into Lake Roosevelt in eastern Washington generated numerous tsunamis after Grand Coulee Dam created the lake on the Columbia River.

- *April 8, 1944 -* A four to five million cubic yard landslide from Reed Terrace generated a 30-foot wave, 5,000 feet away on the opposite shore of the lake about 98 miles above Grand Coulee Dam.

- *July 27, 1949 -* A two to three million cubic yard landslide near the mouth of Hawk Creek created a 65-foot wave that crossed the lake about 35 miles above Grand Coulee Dam. The wave was observed 20 miles away.

- *February 23, 1951 –* A 100,000 to 200,000 cubic yard landslide just north of Kettle Falls created a wave that picked up logs at the Harter Lumber Company Mill and flung them through the mill 10 feet above lake level.

- *April 10 – 13, 1952* – A 15 million cubic yard landslide three miles below the Kettle Falls Bridge created a 65-foot wave that struck the opposite shore of the lake. Some waves were observed six miles up the lake.

- *October 13, 1952* – A landslide 98 miles upstream of Grand Coulee Dam created a wave that broke tugboats and barges loose from their moorings at the Lafferty Transportation Company six miles away. It also swept logs and other debris over a large area above lake level.

- *February 1953* – A series of landslides about 100 miles upstream from Grand Coulee Dam generated a number of waves that crossed the lake and hit the opposite shore 16 feet above lake level. On average, the waves were observed crossing the 5,000-foot wide lake in about 90 seconds.

- *April – August 1953* – Landslides originating in Reed Terrace caused waves in the lake at least 11 different times. The largest wave to hit the opposite shore was 65 feet and observed up to six miles away. Velocity of one of the series of waves was about 45 miles per hour.

1980 Spirit Lake Tsunami

The May 18, 1980 eruption of Mount St. Helens caused a massive tsunami in Spirit Lake. The sliding north face of the volcano slammed into the west arm of the lake, raising its surface an estimated 207 feet and sending a tsunami surging around the lake basin as high as 820 feet above the previous lake level. Displaced water rinsed the valley sides clean of timber and sediment, jamming logs and boulders against the landslide debris. In the east arm of Spirit Lake, the tsunami wave reached nearly 740 feet above old level of the lake, also washing trees off the sides of the valley and into the lake.

Seiche[14, 15]

Seiches are water waves generated in enclosed or partly enclosed bodies of water such as reservoirs, lakes, bays and rivers by the passage of seismic waves (ground shaking) caused by earthquakes. Sedimentary basins beneath the body of water can amplify a seismic seiche. Seismic waves also can amplify water waves by exciting the natural sloshing action in a body of water or focusing water waves onto a section of shoreline.

In a paper currently in review, researchers at the University of Washington and the U.S. Geological Survey indicate that the geology of the sedimentary basin beneath Seattle amplify seismic waves from large and distant earthquakes and contribute to the damaging effects of water waves in local enclosed bodies of water.

Water waves produced by the magnitude 7.9 Denali, Alaska earthquake in November 2002 damaged about 20 houseboats in Seattle's Lake Union, buckling moorings and breaking sewer and water lines. Sloshing action was reported in swimming pools, ponds and lakes around Seattle. Newspaper reports indicate water waves from the magnitude 9.2 Alaska earthquake in 1964 caused similar damage on the lake; sloshing wave action also was reported following the magnitude 7.1 Olympia earthquake in 1949 and the magnitude 6.5 magnitude Seattle earthquake in 1965.

In the paper, researchers further indicate that local amplification of seismic waves could make urban areas above other sedimentary basins in the region particularly vulnerable to seiches or water waves during large earthquakes on the Seattle Fault or the Cascadia Subduction Zone.

Jurisdictions Most Vulnerable to Tsunami[16, 17]

Beaches open to the ocean, by bay entrances or tidal flats and the shores of coastal rivers, and some inland waters, are vulnerable to tsunamis. The Washington coast and the Strait of Juan de Fuca are vulnerable to tsunamis generated at a considerable distance in the Pacific Ocean or by a local Cascadia Subduction Zone earthquake. These areas and the Puget Sound also are vulnerable to tsunamis generated by local crustal earthquakes or by surface and submarine landslides.

Washington began creating tsunami inundation models and maps for its coastal regions using funds from NOAA – Pacific Marine Environmental Laboratory's National Tsunami Hazard Mitigation Program in the late 1990s. To date, tsunami inundation mapping is complete for the southern Washington coast, Neah Bay on the northwestern-most point of the Olympia Peninsula, the Port Angeles area on the Strait of Juan de Fuca, Port Townsend on the northeastern corner of the Olympic Peninsula, and Seattle; modeling is complete for Whidbey Island, Anacortes, and Bellingham. Modeling for the Olympia, Tacoma, Bremerton, and Everett areas of Puget Sound has yet to be scheduled.

The National Tsunami Hazard Mitigation Program generates tsunami models and the Washington Department of Natural Resources Division of Geology and Earth Resources prepares tsunami maps.

Southern Washington Coast, Port Angeles, Port Townsend[18, 19, 20]

The National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts has developed tsunami models to help jurisdictions along the Southern Washington Coast, and Port Angeles and Port Townsend prepare evacuation plans for a future tsunami. The models use a moment magnitude 9.1 earthquake on the Cascadia Subduction Zone off the Washington coast as the generator of the tsunami. Projects covering these areas have identified at-risk communities (all census designated and incorporated places within one kilometer of the coast) and developed arrival times and wave elevations for them.

For communities on the outer coast, the first wave crest is predicted to arrive between 30 and 60 minutes after the earthquake; in Willapa Bay and Grays Harbor, the first crest is not expected to arrive for more than an hour. Significant flooding can occur before the first wave crest because a Cascadia Subduction Zone earthquake is expected to lower the ground surface along the coast. Flooding of areas less than six feet above tide stage is expected immediately. Maximum flooding depth and extent will depend on tide height at the time of tsunami arrival.

For the Port Angeles and Port Townsend areas, the crest of the first wave is expected within 90 minutes of the earthquake, with significant flooding before the crest.

Grays Harbor County

Communities with population at risk:

Aberdeen	Hoquiam	Ocean Shores
Cohassett Beach	Markham	Oyehut-Hogans Corner
Copalis Beach	Moclips	Taholah
Grayland	Ocean City	Westport

Projected at-risk population: 17,477

Pacific County

Communities with population at risk:

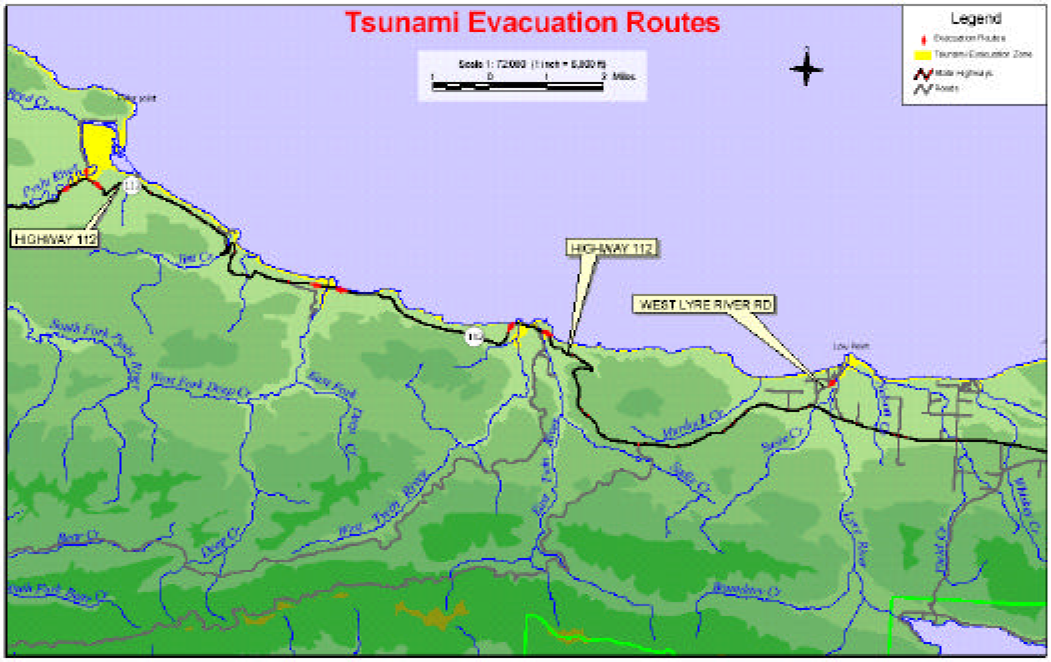
Bay Center	Ocean Park	South Bend
Ilwaco	Raymond	Tokeland
Long Beach		

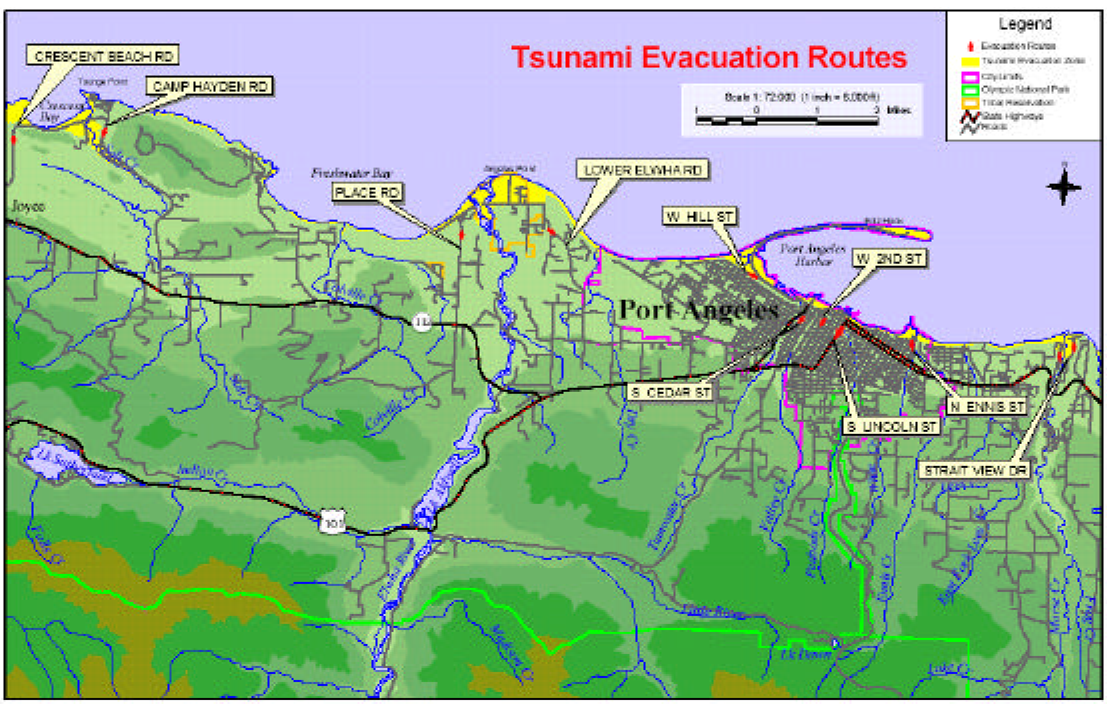
Projected at-risk population: 5,587

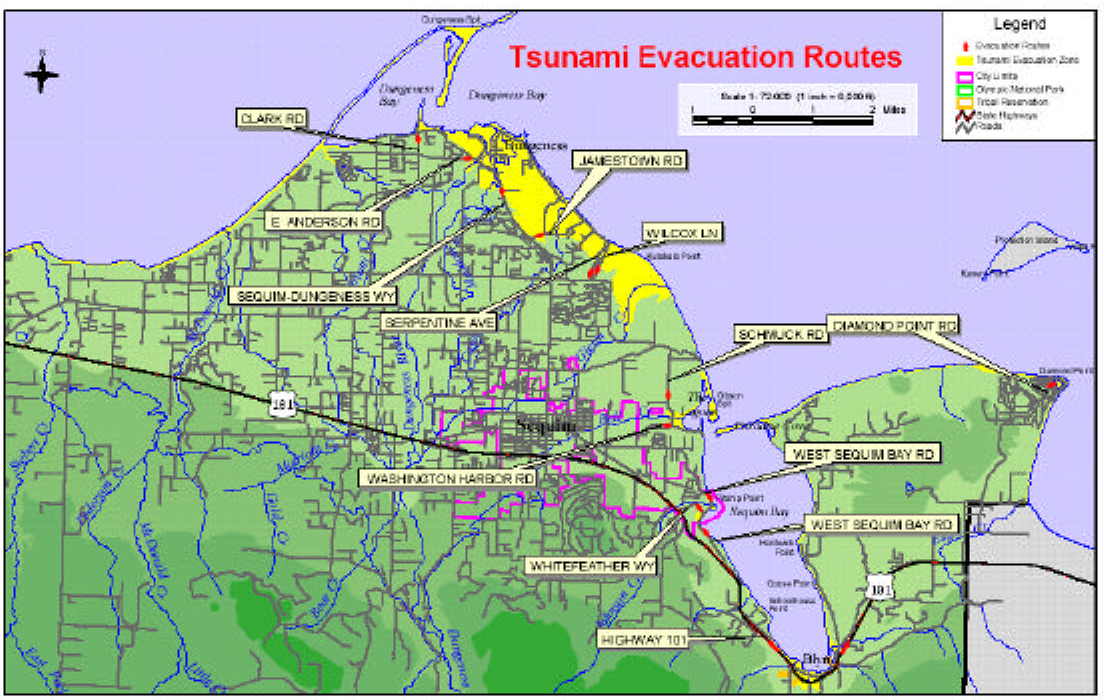
Clallam County

Communities with population at risk:
La Push Neah Bay Port Angeles Sequim

Projected at-risk population: 11,064


Tsunami Evacuation Routes
Legend
HIGHWAY 112
HIGHWAY 112
WEST LYRE RIVER RD


Tsunami Evacuation Routes
Legend
CRESCENT BEACH RD
CAMP HAYDEN RD
PLACE RD
LOWER ELWHA RD
W HILL ST
W 2ND ST
Port Angeles
S CEDAR ST
S LINCOLN ST
N ENNIS ST
STRAIT VIEW DR

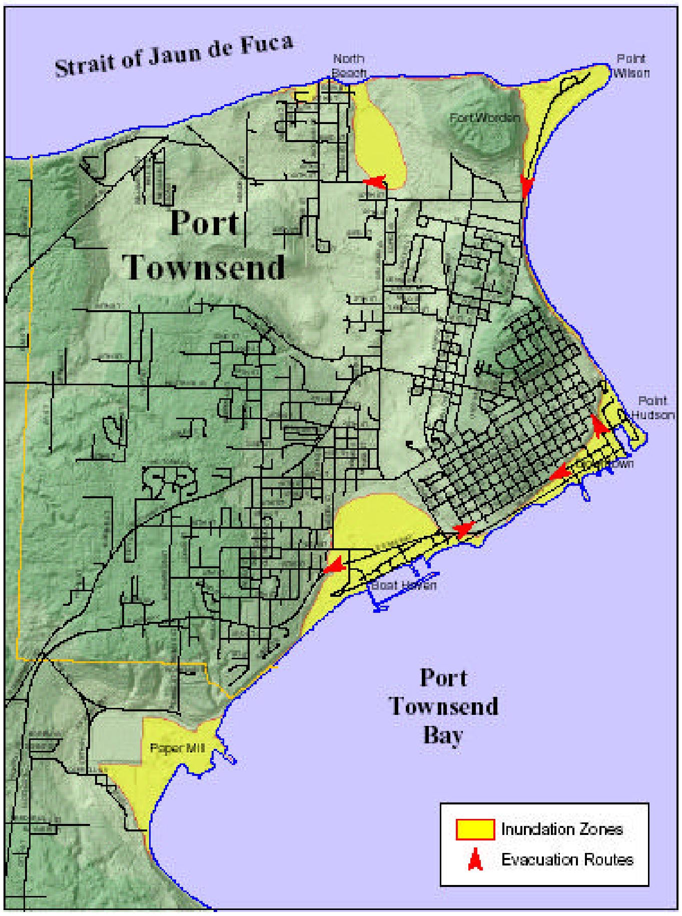


Tsunami inundation and evacuation maps from Clallam County Department of Community Development, September 2003

Jefferson County

Communities with population at risk:
Marrowstone Island Port Townsend
Port Hadlock-Irondale

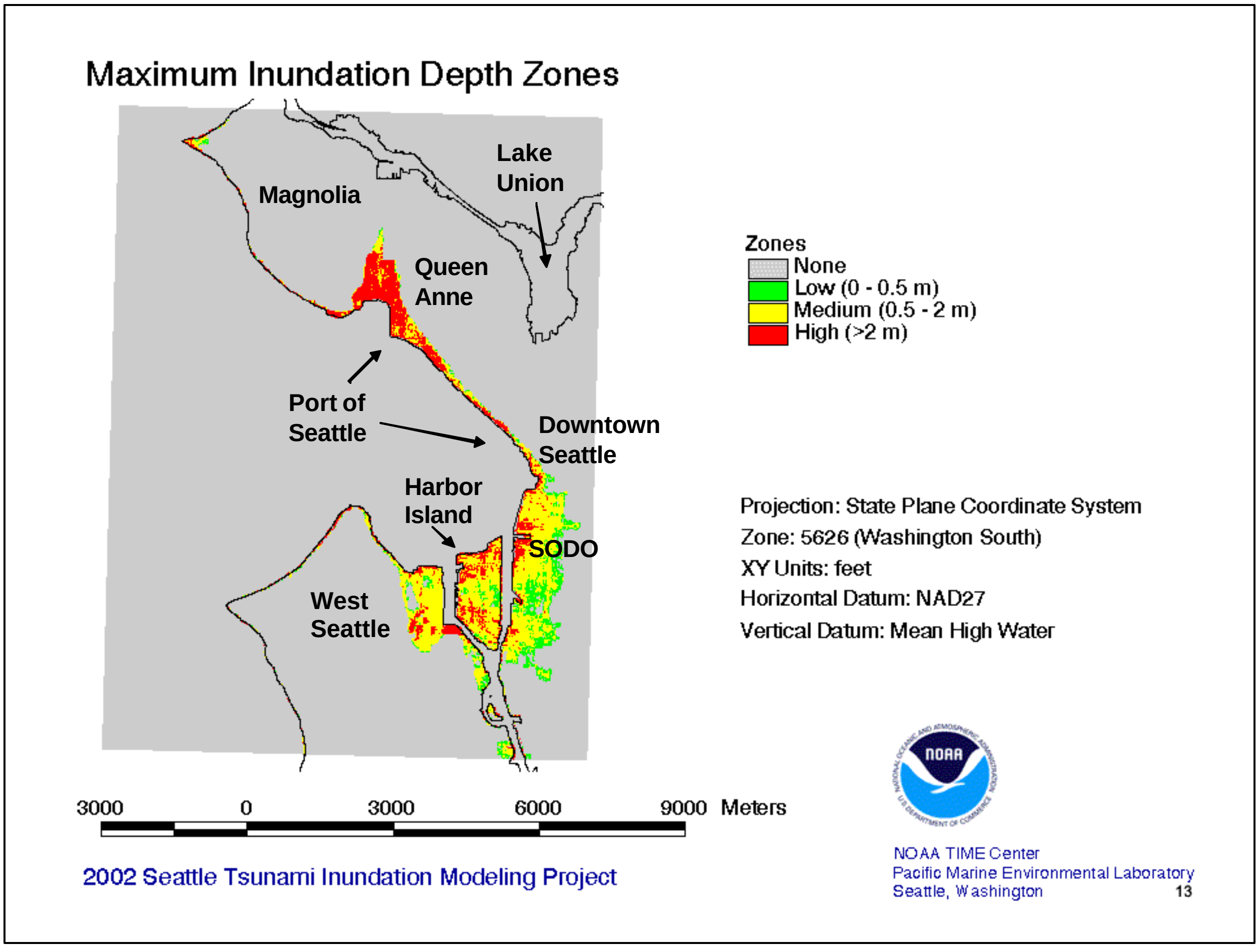
Projected at-risk population: 9,612



Tsunami inundation and evacuation map from Jefferson County Department of Central Services, September 2003

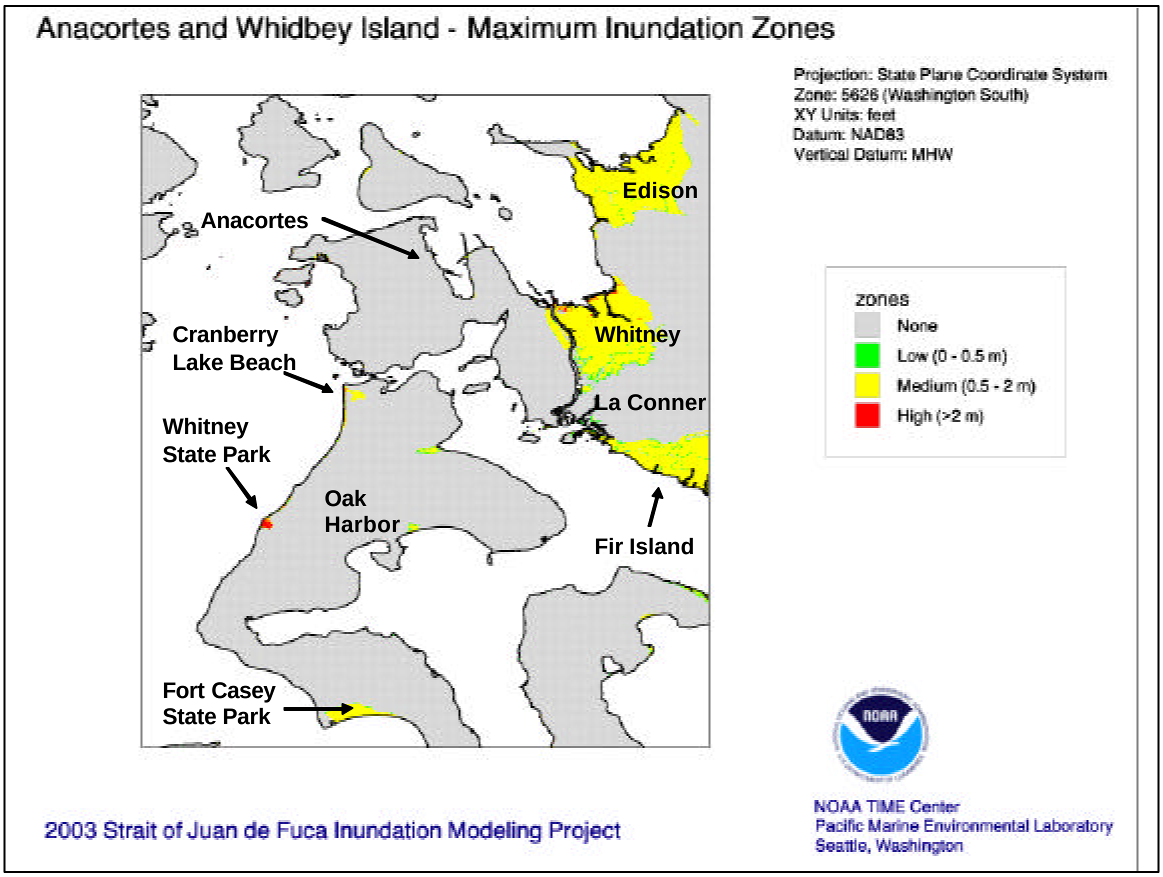
Seattle[21]

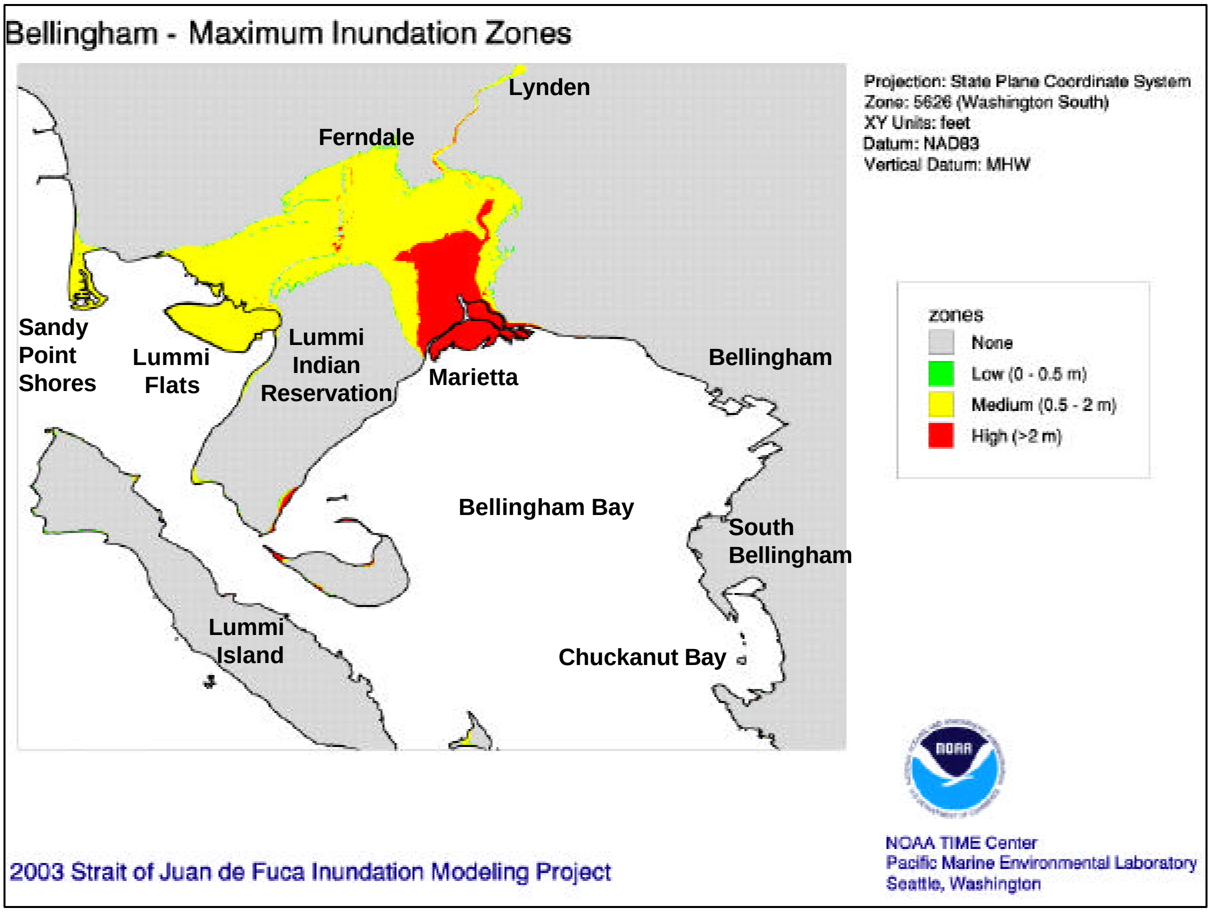
The National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts has developed a tsunami inundation model for Elliott Bay in Seattle using as an initiating event a magnitude 7.3 earthquake on the Seattle Fault, which roughly parallels Interstate 90 through Seattle. The area modeled includes the portions of Seattle highlighted on the map below. The projected at-risk population of this area has not been determined.



Strait of Juan de Fuca[22]

The National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts has developed a tsunami inundation model for communities at the east end of the Strait of Juan de Fuca. The model uses an initiating event of a magnitude 9.1 earthquake on the Cascadia Subduction Zone off the Pacific Coast. The area modeled includes the highlighted areas on the maps below of the areas in Island, Skagit and Whatcom Counties. The projected at-risk population has not been determined.





Puget Sound – Everett to Olympia[23]

Future projects planned by the National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts will develop tsunami inundation models for the following census designated and incorporated places within one kilometer of the coast.

King County (outside Seattle)

Communities potentially at risk:

Burien	Federal Way	Vashon
Des Moines	Normandy Park	

Projected at-risk population: 45,996

Kitsap County

Communities potentially at risk:

Bain Bridge Island	Navy Yard City	Silverdale
Bremerton	Parkwood	Suquamish

Erlands Point	Port Orchard	Tracyton
Manchester	Poulsbo	

Projected at-risk population: 61,731

Mason County

Community potentially at risk:
Allyn-Grapeview

Projected at-risk population: 1,994

Pierce County

Communities potentially at risk:

Artondale	Gig Harbor	Tacoma
DuPont	Ruston	University Place
Fox Island	Steilacoom	

Projected at-risk population: 55,900

Snohomish County

Communities potentially at risk:

Edmonds	Picnic Point-North Lynnwood	Warm Beach
Everett	Shaker Church	Weallup Lake
Marysville	Stanwood	Woodway
Mukilteo	Tulalip Bay	

Projected at-risk population: 55,661

Thurston County

Communities potentially at risk:

Lacey	Priest Point
Olympia	Tumwater

Projected at-risk population: 15,939

State Agency Structures At Risk **PRELIMINARY ASSESSMENT**

Number and Function of Buildings	No. of Affected Staff / Visitors / Residents	Approx. Value of Owned Structures	Approx. Value of Contents All Buildings
Total at-risk buildings: State agencies participating in this plan identified 67 facilities as being potentially at-risk to direct damage or to the indirect impacts of tsunami (utility services reductions, transportation restrictions, etc.).	4,260	$98,713,426	$85,958,731

Function of at-risk buildings: Included in the state facilities potentially at-risk to the direct and indirect impacts of tsunami are the following:

- Buildings on the campuses of the Naselle Youth Camp for juvenile offenders and the marine laboratory of Western Washington University
- Laboratory buildings on the main campus of the University of Washington.
- About 56 general and client services offices that include those serving individuals and families on public assistance, providing employment and training services, driver licensing, and liquor sales.

One state highway considered an emphasis corridor because of its importance to movement of people and freight is potentially at-risk to tsunami as it traverses near vulnerable shorelines:

1. U.S. Highway 101

Additionally, ferry landings in Anacortes, Bainbridge Island, Bremerton, Clinton, Fauntleroy, Keystone, Mukilteo, Port Townsend, the San Juan Islands, Seattle, Southworth, Tacoma, and Vashon Island are potentially at risk because of their location on vulnerable shoreline areas.

Total at-risk critical facilities: State agencies participating in this plan identified 40 critical facilities as being potentially at-risk to direct damage or to the indirect impacts of tsunami (utility services reductions, transportation restrictions, etc.).	2,907	$71,993,300	$28,750,709

Function of at-risk critical facilities: Included in the state facilities potentially at-risk to the direct and indirect impacts of tsunami are the following:

- Buildings on the campuses of the Naselle Youth Camp for juvenile offenders and the marine laboratory of Western Washington University
- Laboratory buildings on the main campus of the University of Washington.
- About 29 general and client services offices that include those serving individuals and families on public assistance, providing employment and training services, driver licensing, and liquor sales.

One state highway considered an emphasis corridor because of its importance to movement of people and freight is potentially at-risk to tsunami as it traverses near vulnerable shorelines:

1. U.S. Highway 101

Additionally, ferry landings in Anacortes, Bainbridge Island, Bremerton, Clinton, Fauntleroy, Keystone, Mukilteo, Port Townsend, the San Juan Islands, Seattle, Southworth, Tacoma, and Vashon Island are potentially at risk because of their location on vulnerable shoreline areas.

[1] *Tsunamis*, Washington Department of Natural Resources Division of Geology and Earth Resources, online fact sheet, <http://www.wa.gov/dnr/htdocs/ger/tsunami.htm>, (March 28, 2003).

[2] *NOAA and Tsunamis*, National Tsunami Hazard Mitigation Project, National Oceanic and Atmospheric Administration, online fact sheet, <http://www.publicaffairs.noaa.gov/grounders/tsunamis.html>, (March 26, 2003).

[3] *Tsunamis: Frequently Asked Questions*, National Tsunami Hazard Mitigation Project, National Oceanic and Atmospheric Administration, December 20, 2002, <http://www.pmel.noaa.gov/tsunami-hazard/tsunami_faqs.htm>, (May 2, 2003).

[4] *Frequently Asked Questions About Tsunamis*, International Tsunami Information Center, National Oceanic and Atmospheric Administration, <http://www.prh.noaa.gov/pr/itic/Tsu_FAQs.htm>, (November 4, 2002).

[5] Timothy J. Walsh et al., *Tsunami Hazard Map of the Southern Washington Coast: Modeled Tsunami Inundation from a Cascadia Subduction Zone Earthquake*, Washington Department of Natural Resources Division of Geology and Earth Resources, Geologic Map GM-49, October 2000.

[6] Thomas J. Sokolowski, *The Great Alaskan Earthquake and Tsunamis of 1964*, West Coast and Alaska Tsunami Warning Center, <http://wcatwc.gov/64quake.htm>, (March 25, 2003).

[7] *April 13, 1949 Puget Sound Tsunami – Salmon Beach Narrative*, West Coast and Alaska Tsunami Warning Center, National Oceanic and Atmospheric Administration, <http://wcatwc.noaa.gov/web_tsus/19490413/narrative1.htm>, (March 26, 2003).

[8] *Tsunamis Affecting the West Coast of the United States 1806 – 1992,* National Geophysical Data Center Key to Geophysical Records Documentation No. 29, National Oceanic and Atmospheric Administration, December 1993.

[9] High Shipman, *The Fall of Camano Head: A Snohomish Account of a Large Landslide and Tsunami in Possession Sound During the Early 1800s*, TsuInfo Alert, Volume 3, No. 6, December 2001.

[10] *Tsunamis Affecting the West Coast of the United States 1806 – 1992,* National Geophysical Data Center Key to Geophysical Records Documentation No. 29, National Oceanic and Atmospheric Administration, December 1993.

[11] Don J. Miller, *Giant Waves in Lituya Bay Alaska – Shorter Contributions to General Geology*, U.S. Department of the Interior, Geological Survey Professional Paper 354-C, 1960.

[12] Lee Walkling, *Infrequently Asked Questions*, TsuInfo Alert, Volume 1, No. 2, February 1999.

[13] Oral communication from Timothy J. Walsh, Chief Geologist, Washington Department of Natural Resources, May 1, 2003.

[14] *What Causes Damage*, University of Washington, Pacific Northwest Seismograph Network fact sheet, <http://www.geophys.washington.edu/SEIS/PNSN/INFO_GENERAL/NQT/what_causes_damage.html>, (August 11, 2003).

[15] A. Barberopoulou et al., *Local Amplification of Seismic Waves from the M7.9 Alaska Earthquake and Damaging Seiches in Lake Union, Seattle, Washington*, currently in review, August 4, 2003 manuscript.

[16] National Tsunami Hazard Mitigation Program, National Oceanic and Atmospheric Administration Pacific Marine Environmental Laboratory, <http://www.pmel.noaa.gov/tsunami/time/wa/population/index.shtml>, (March 26, 2003).

[17] V.V. Titov et al., 2003. NOAA TIME Seattle Tsunami Mapping Project: Procedures, data sources, and products, NOAA Technical Memo OAR PMEL-124 (in preparation).

[18] General information and population figures from *TIME Workshop – At-Risk Population*, NOAA National Tsunami Hazard Mitigation Program Center for Tsunami Inundation Mapping Efforts, <http://www.pmel.noaa.gov/tsunami/time/wa/population/wa_1.shtml>, (March 26, 2003).

[19] Timothy J. Walsh et al., *Tsunami Hazard Map of the Port Angeles, Washington, Area*, Washington Department of Natural Resources Division of Geology and Earth Resources, Open File Report 2002-1, August 2002.

[20] Timothy J. Walsh et al., *Tsunami Hazard Map of the Port Townsend, Washington, Area*, Washington Department of Natural Resources Division of Geology and Earth Resources, Open File Report 2002-2, August 2002.

[21] *TIME Workshop – At-Risk Population*, NOAA National Tsunami Hazard Mitigation Program Center for Tsunami Inundation Mapping Efforts, <http://www.pmel.noaa.gov/tsunami/time/wa/population/wa_2.shtml>, (March 26, 2003).

[22] Product Reports, 2003 Eastern Strait of Juan de Fuca Inundation Modeling Project, NOAA National Tsunami Hazard Mitigation Program Center for Tsunami Inundation Mapping Efforts, July 2003.

[23] *TIME Workshop – At-Risk Population*, NOAA National Tsunami Hazard Mitigation Program Center for Tsunami Inundation Mapping Efforts, < http://www.pmel.noaa.gov/tsunami/time/wa/population/wa_3.shtml>, (March 26, 2003).